Attachment – Nichols to Chu, May 29, 2009 Updated: June 2, 2009

Hydrogen and Fuel Cells: Issues and Status

Summary:
All promising low-carbon non-petroleum transportation options, including hydrogen fuel cell vehicles, battery electric vehicles, and advanced liquid biofuels in combustion engines, face significant technical, resource, and market challenges. Hydrogen and fuel cells show great potential and have met or exceeded nearly all of the technical milestones set out by US DOE. Several major automakers are pursuing early market testing with consumers beginning this year and are expected to ramp up production to nearly 50,000 vehicles in California by 2017. Ultimately the market will decide which technologies are the winners, but given the critical importance to our long term climate and energy security goals, the best approach is to pursue and invest in a portfolio of the most promising options.

Issue #1: Fuel cell vehicles (FCVs) are too expensive

Status: Fuel cell system durability has improved and costs have been reduced through R&D. FCVs in volume are expected to be cost-competitive with other advanced vehicles.
Even with today's design and high costs of materials, fuel cell systems are fast approaching the cost of advanced hybrid systems. Recent DOE-sponsored third-party engineering cost analyses have estimated automotive fuel cell systems based on today's design, including balance of plant, will cost $73/kW at high volume ($6,400 for 80 kW system)[1]. Improvements in system design, including lower catalyst loadings, are expected to reduce this number further in the near future.

A detailed analysis by Kromer and Heywood at MIT[2] shows that with minor improvements in system cost, a mass produced fuel cell vehicle with 350-mile all-electric range is projected to cost only $3600 more than a conventional car and only $700 more than an advanced hybrid (see graph below). This is a lower incremental cost than a plug-in hybrid with 30 miles all-electric range ($4300 more) and a full battery-electric vehicle (over $10,000 more.)

Table 1 : DOE targets[3] and MIT inputs[2] for fuel cell, hydrogen and battery status:

			DOE Targets	DOE Targets	MIT Input	Status
Fuel Cell	Year		2010	2015	2030	2008
Fuel Cell	Fuel Cell System Cost	($/kW)	45	30	50	73[a]
Fuel Cell	Hydrogen Storage Cost	($/kWH)	TBD	TBD	15	15.5 (350 bar) 23 (700 bar)[b]
Fuel Cell	Hydrogen Storage Density	(kWh/L)	0.9	1.3	0.8	0.58 (350 bar) 0.72 (700 bar)[b]
Battery	Year		2012	2014	2030	2009
Battery	Range	(miles)	10	40	30	10
Battery	Battery Cost	($/kWh)	500	300	320	1000+[c]
Battery	Battery Storage Density	(kWh/kg)	0.057	0.096	0.135	0.043[c]

[a] *DOE progress report to Congress.* January, 2009. http://www.hydrogen.energy.gov/pdfs/epact_report_sec811.pdf (The projected high-volume manufacturing cost of automotive fuel cell systems has decreased from $275/kW in 2002 to $73/kW in 2008).

[b] Dillich, S. *Hydrogen Storage.* Presented at DOE annual merit review May 19, 2009. (System volumetric capacity 17-18 g/L (350 bar) and 18-25 g/L (700 bar): average of 17.5 g/L and 21.5 g/L, respectively, yields 0.58 kWh/L and 0.72 kWh/L).

[c] Howell, D. *Energy Storage R&D Overview.* Presented at DOE annual merit review May 19, 2009.

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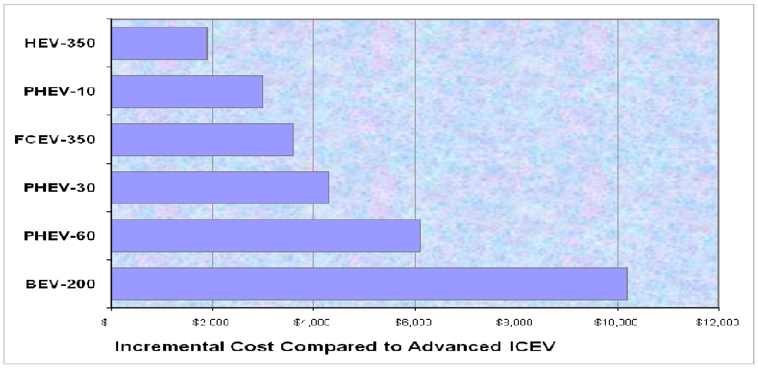
[1] Includes materials + manufacturing + return on capital at 500,000 units/year. For details see: http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fctt_pemfc_cost_review_0908.pdf ; http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/dti_fc_cost_analysis_dfma.pdf

[2] Kromer & Heywood, "Electric Powertrains: Opportunities & Challenges in the U.S. Light-Duty Vehicle Fleet Report # LFEE 2007-03RP, MIT, May, 2007, Table 53

[3] DOE progress report to Congress, Jan. 2009 http://www.hydrogen.energy.gov/pdfs/epact_report_sec811.pdf

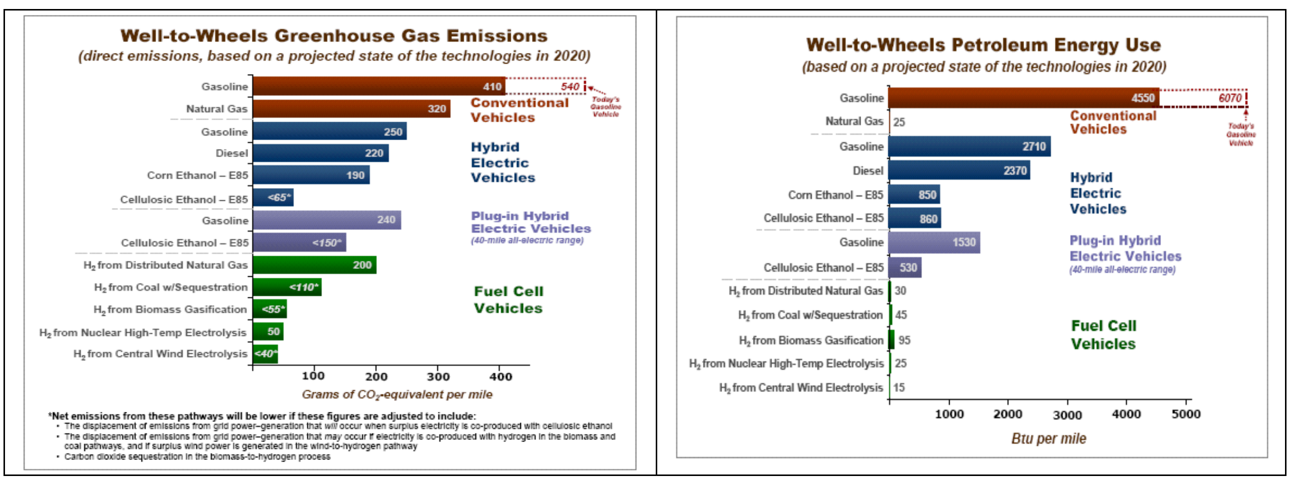


Additionally, fuel cell durability has also improved dramatically including freeze-capable systems lasting 1,900 hours in 2008 in the field (up from 950 hrs in 2006) and 7,300 hours in the lab[4] (2015 commercialization target = 5,000).

Issue #2: It is inefficient to make hydrogen from natural gas

Status: Hydrogen from natural gas is clean, energy efficient and can be used to transition to renewable and other low carbon sources.

Hydrogen is produced in large quantities today, primarily from natural gas. The DOE compared "well-to-wheel" emissions of GHGs and petroleum energy use from various pathways, and the results show that FCVs using hydrogen are one of the cleanest vehicle technologies. FCVs using hydrogen from natural gas emit 63% fewer GHGs than today's gasoline vehicle, and 37% fewer GHGs than natural gas vehicles. Just as with electricity, future methods of making hydrogen will utilize renewable feedstocks and carbon sequestration to reduce GHGs further. FCVs using hydrogen from biomass emit 90% fewer GHGs than today's gasoline vehicle and 63% fewer GHGs than a PHEV running on cellulosic ethanol using the national grid.[5]



Improving vehicle efficiency, using advanced low-carbon biofuels, and deploying hydrogen fuel cell vehicles can all significantly reduce petroleum use and carbon emissions by mid-century. The National Research Council analysis recommends a 'portfolio approach' to achieve deep reductions in GHG emissions and petroleum consumption through 2050[6].

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[4] Cycle testing at 80C – see: http://www1.eere.energy.gov/hydrogenandfuelcells/accomplishments.html

[5] http://www.hydrogen.energy.gov/pdfs/9002_well-to-wheels_greenhouse_gas_emissions_petroleum_use.pdf; also see: CARB Low Carbon Fuel Standard, http://www.arb.ca.gov/regact/2009/lcfs09/lcfsisor1.pdf

[6] Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, NRC 2008

Issue #3: Building a hydrogen infrastructure is too difficult and costly
Status: Hydrogen can be cost-competitive with gasoline and stations can be deployed using a coordinated cost-effective, regional strategy.
Maintaining our existing global gasoline supply system over the next 25 years is estimated to cost more than $160 Billion annually[7]. The main question for hydrogen supply and refueling is how much public or private investment will be needed to achieve profitability. When produced and distributed in high-volume, hydrogen can be made efficiently from a variety of feedstocks including natural gas, biomass, and coal with sequestration at levelized costs of $3-6/kg[3], which, when adjusted for the efficiency of the FCV is comparable to $1.50-$3/gallon of gasoline in today's vehicles[8].

Several studies have shown that it is possible to roll-out infrastructure regionally concurrently with vehicle deployment to maximize customer utility and minimize costs for early markets[9]. In assessing a transition to hydrogen fuel cell vehicles, the National Research Council modeled a fuel production pathway to supply fuel for 1.8 million vehicles through 2020 and 10 million vehicles through 2025[10]. To enable such a transition, approximately $8 billion would be needed over 16 years to cover the entire capital cost of the early hydrogen infrastructure to a self-sustaining FCV market[6]. The recently released CaFCP action plan[11], details a strategy for a coordinated roll-out of 46 stations in California to serve 4,300 fuel cell vehicles by 2014 and begin growing the network to serve more than 40,000 cars through 2017 at a total government and industry cost of $180M.

NRC estimates it would cost $2.2 million to build a hydrogen fueling station that could support 1500 FCVs, or $1500 per vehicle. By comparison, the Idaho National Laboratory[12] estimates that the average cost of adding a home 120V, 20A circuit to charge one PHEV would be $878/vehicle, and a 240V circuit needed for a PHEV-30 or PHEV-40 would cost $1500-2100/vehicle. Furthermore, the NRC estimates it will cost less than $600M/year for all public and private R&D costs plus total vehicle and hydrogen supply costs to sustain hydrogen and fuel cells as a viable option through 2014.

Issue #4: Breakthroughs are needed in hydrogen storage
Status: Compressed hydrogen tanks are safe and provide adequate range in a reasonable volume
The Department of Energy has monitored and evaluated real-world performance of 140 fuel cell vehicles which have safely accumulated over 85,000 hours of operation and 1.9 million miles. Using crash-tested compressed-hydrogen storage on board the vehicles, second generation FCVs exceeded the 250-mile DOE range target for 2008. For example, the Honda Clarity using 350 bar compressed hydrogen storage achieved EPA-adjusted fuel economy at 77 mpg city/ 67 mpg highway and 280 mile range[13]. The 2009 Toyota FCHV using 700 bar storage has a stated range of 480 miles operating on the Japanese 10/15 drive cycle.[14] Additionally, for a given quantity of energy storage, compressed hydrogen storage costs are expected be 1/20 that of advanced lithium-ion battery cost ($15/KWH vs. $320/KWH – see Table 1 for references).

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[7] http://www.npchardtruthsreport.org/ commissioned by former DOE Secretary Bodman
[8] Fuel cell vehicles are at least 2-3 times more efficient than a comparable gasoline vehicle.
[9] Melendez, M., Milbrandt, A. *Geographically Based Hydrogen Consumer Demand and Infrastructure Analysis: Final Report.* October 2006. NREL. http://www.nrel.gov/hydrogen/pdfs/40373.pdf
[10] Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, NRC 2008, table 6.5
[11] http://www.fuelcellpartnership.org/hydrogen-fuel-cell-vehicle-and-station-deployment-plan
[12] Morrow, K., D. Karner, J.Fancfort, "Plug-in hybrid electric vehicle charging infrastructure review," Final Report INL/EXT-08-15058, Idaho National Laboratory, November 2008
[13] http://www.fueleconomy.gov/feg/fcv_sbs.shtml
[14] http://pressroom.toyota.com/pr/tms/document/2009ToyotaFCHV_FactSheet.pdf